ALICE fixed-target project

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Journées du labex P2IO 2022

December 1st 2022, Orsay

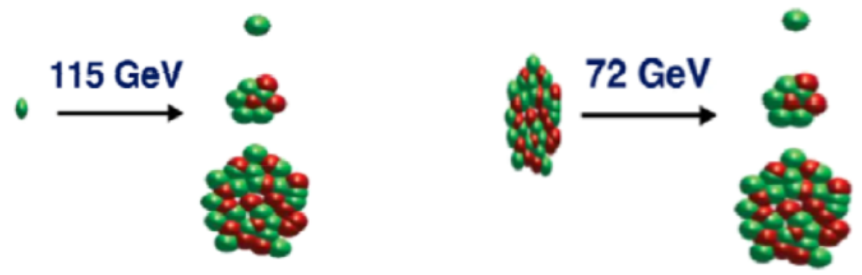
- Physics motivations
- Implementation of a fixed-target in ALICE at the LHC
- Target system conceptual design
- Outlook

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement STRONG – 2020 - No 824093

Fixed target mode at LHC

Fixed target experiments @ LHC

•Energy range: 7 TeV proton / 2.76 A TeV Pb LHC beams on a fixed target



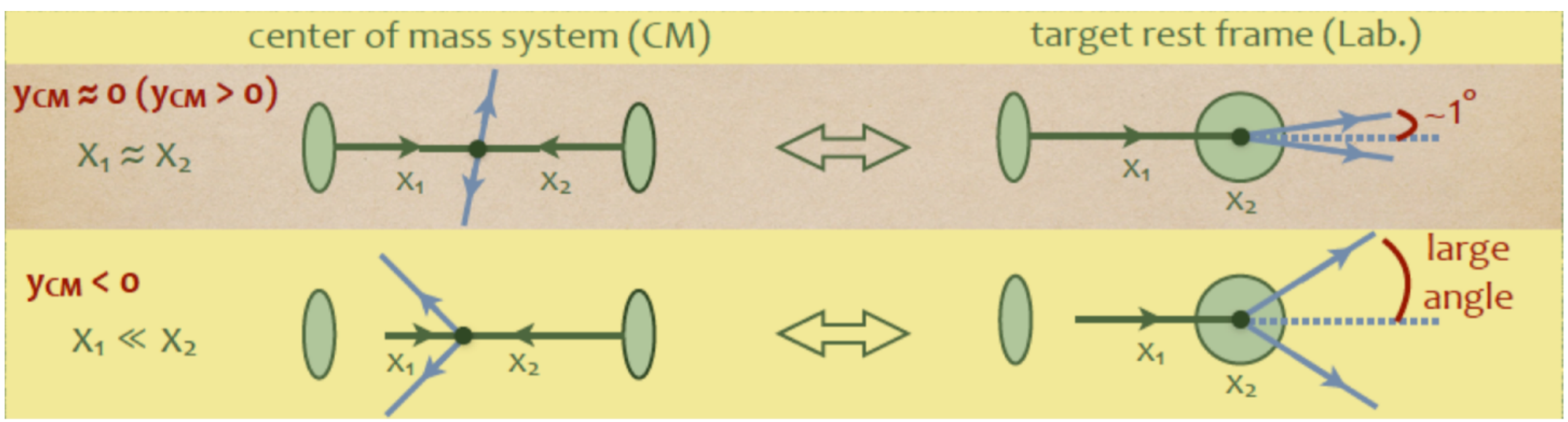
beam type	CM energy $\sqrt{s_{(NN)}}$	boost $\gamma=\sqrt{s}/2m$	y shift
proton (E = 7 TeV)	115 GeV	61	4.8
lead (E = 2.76 A.TeV)	72 GeV	38	4.2

→ most energetic fixed-target experiment: center-of-mass energy in-between SPS at CERN and nominal RHIC

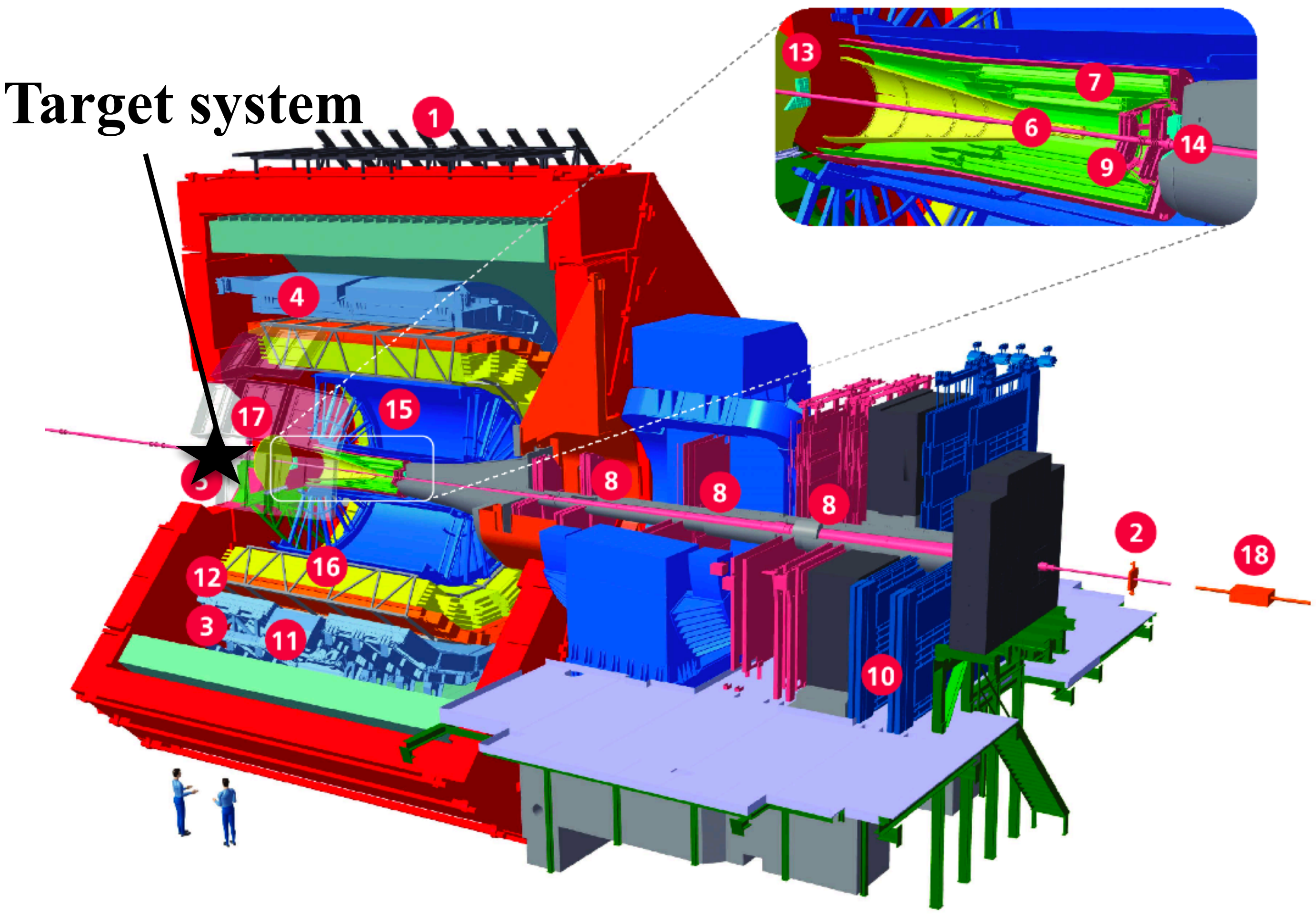
Already running using SMOG and SMOG2 gaseous target at LHCb

Rapidity range

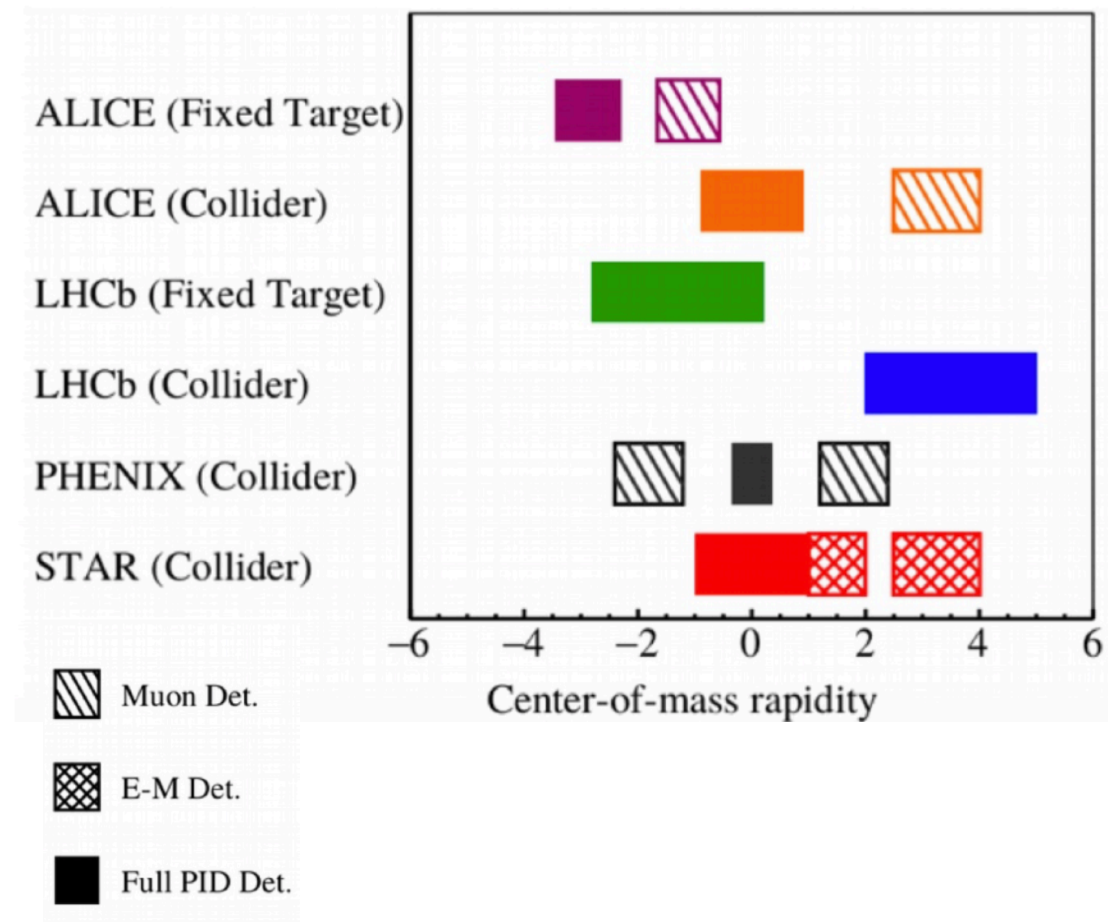
- Entire center-of-mass forward hemisphere ($y_{CM} > 0$) within 1 degree
- Easy access to (very) large backward rapidity range ($y_{CM} < 0$) and large parton momentum fraction in the target (x_2)



Main strengths of the ALICE detector in fixed-target mode



proton beam and $z_{target} = -4.7$ m

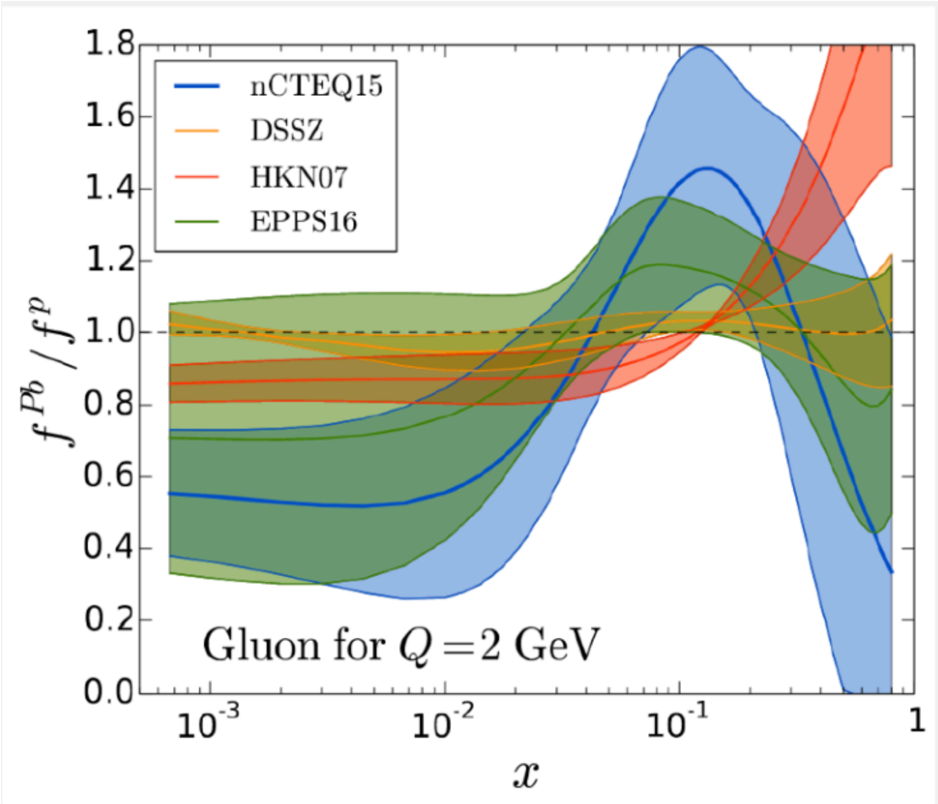


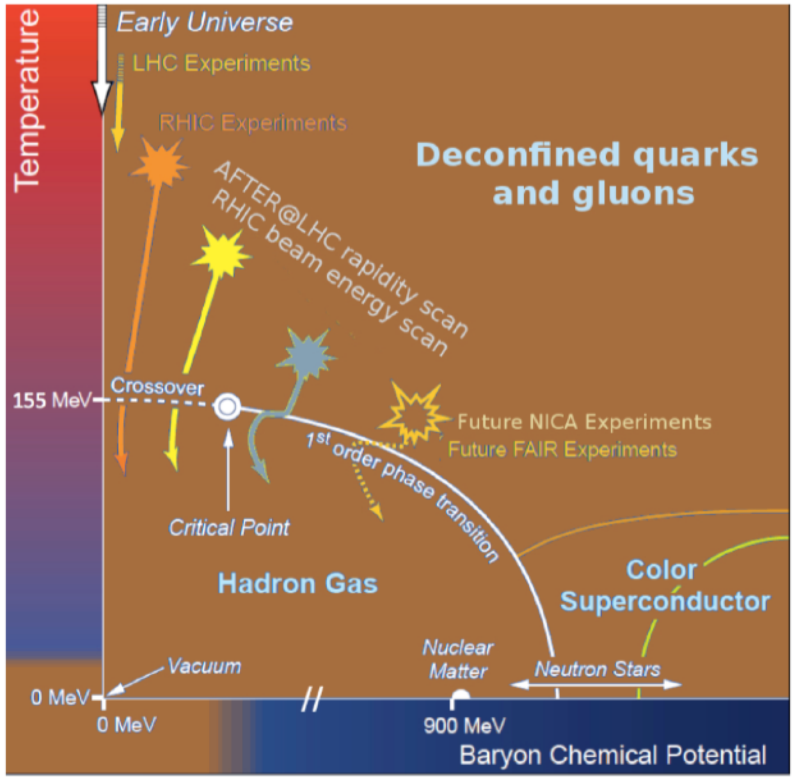
- Large rapidity coverage
  - ALICE muon arm (+ Muon Forward Tracker) can access the mid- (y_{cms} close to ~0) to backward rapidity region
    - Quarkonium detection down to zero p_T
  - ALICE central barrel probes very large negative rapidity region: $y_{cms} \sim -3$ for $z_{target} \sim -4.7$ m
    - Excellent PID capabilities, particle detection down to low p_T

Physics motivations

Physics programme with a fixed target mode with ALICE at LHC: *Phys.Rept.911(2021)1-83* *ESPP document*

- Advance our understanding of the **high-x gluon, antiquark and heavy-quark content in the nucleon and nucleus and its connection to astroparticles**
  - Structure of nucleon and nucleus at high-x poorly known
  - Study possible EMC effect in nuclei
  - Existence of possible non-perturbative source of c/b quarks in the proton: useful for high energy neutrino and cosmic ray physics
- Study the **quark-gluon plasma** between SPS and RHIC energies over a broad rapidity domain
  - Explore the longitudinal expansion of QGP formation
  - Study collectivity in small systems
  - Test factorization of Cold Nuclear Matter effects with Drell-Yan

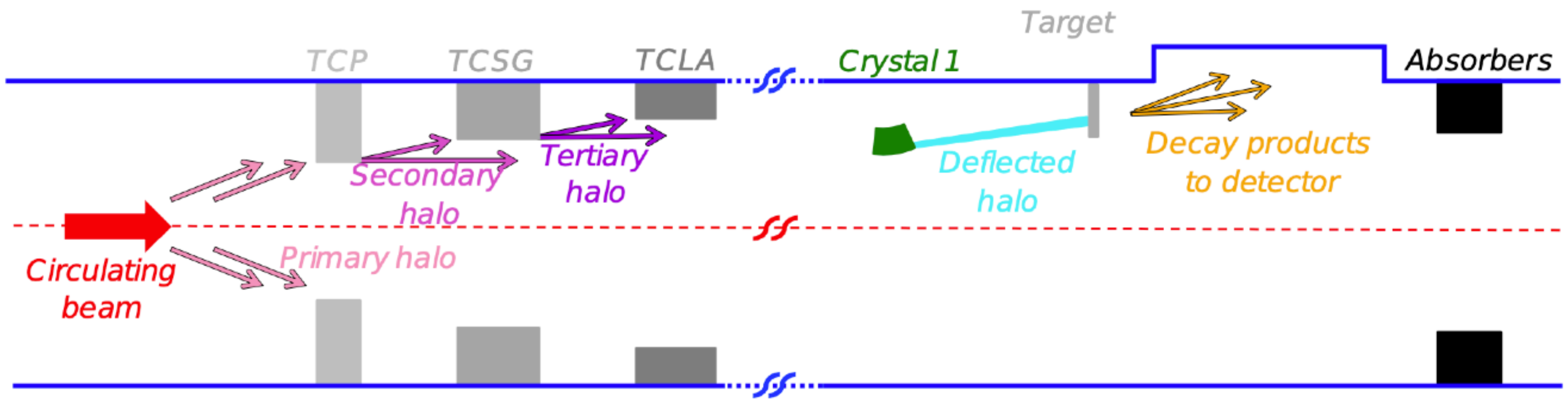


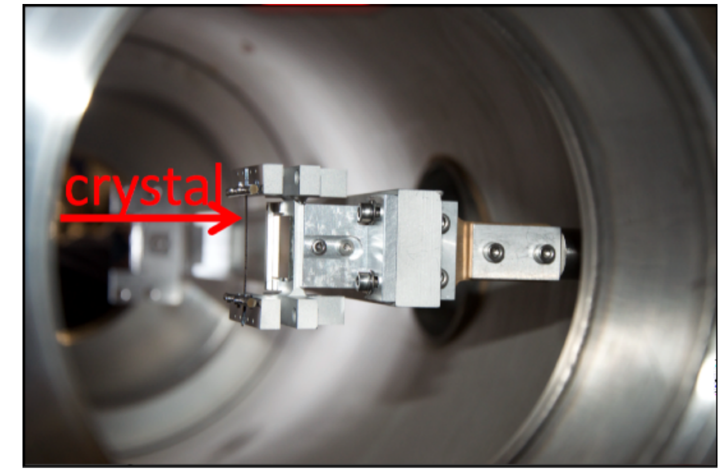


Fixed target implementation in ALICE

Physics Beyond Collider forum: pbc.web.cern.ch

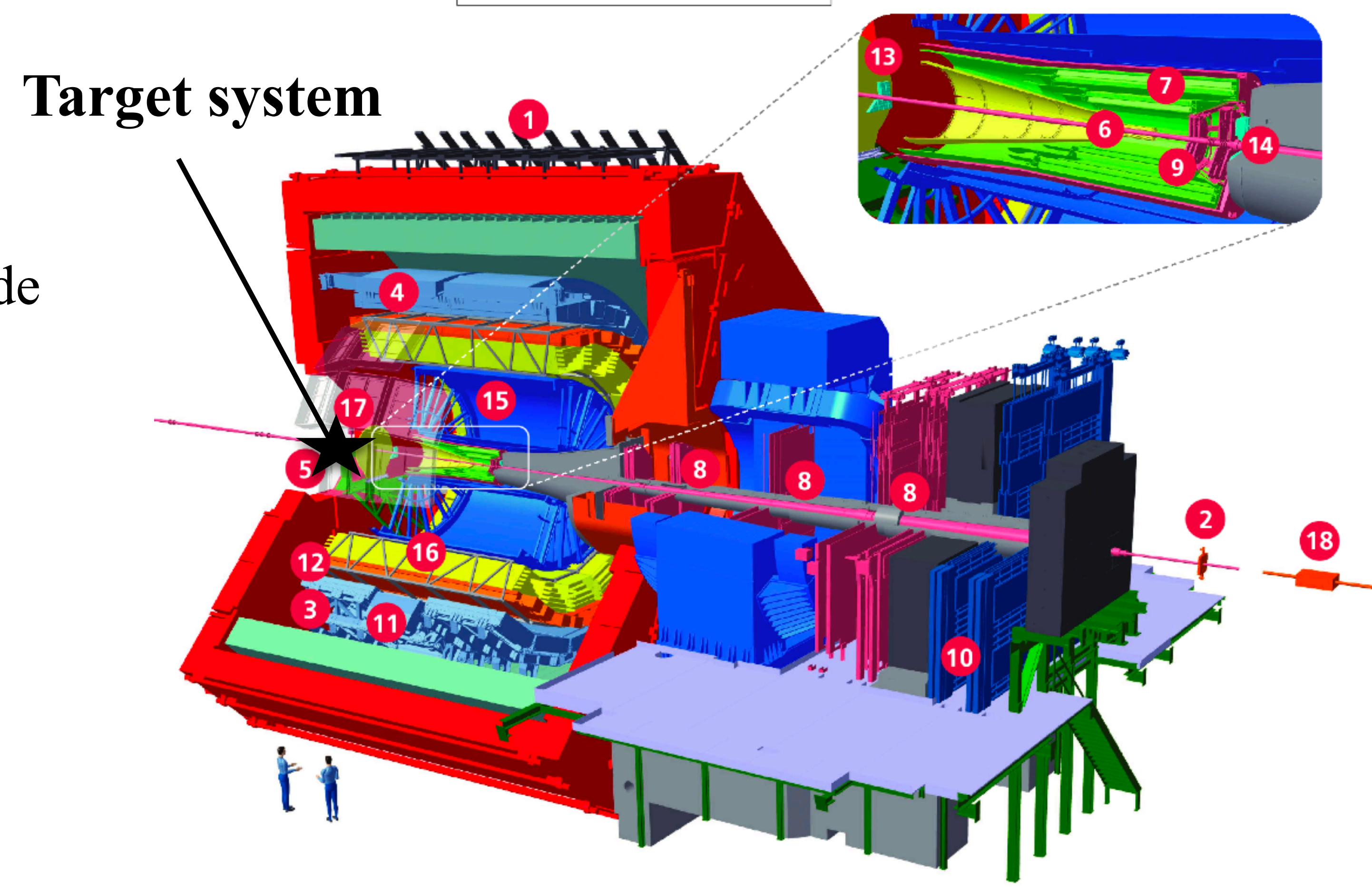
Cern Yellow Report, Vol. 4 (2020), DOI:10.23731/CYRM-2020-004





Graphics: D. Mirarchi

- Beam splitting thanks to a bent crystal
- Part of the secondary halo is channeled by the crystal and deflected towards a solid target inside the beam pipe close to ALICE detectors
- A system of absorbers is placed to intercept the non interacting beam halo
- Aim for an installation during LS3 (2026-2028) for LHC Run 4

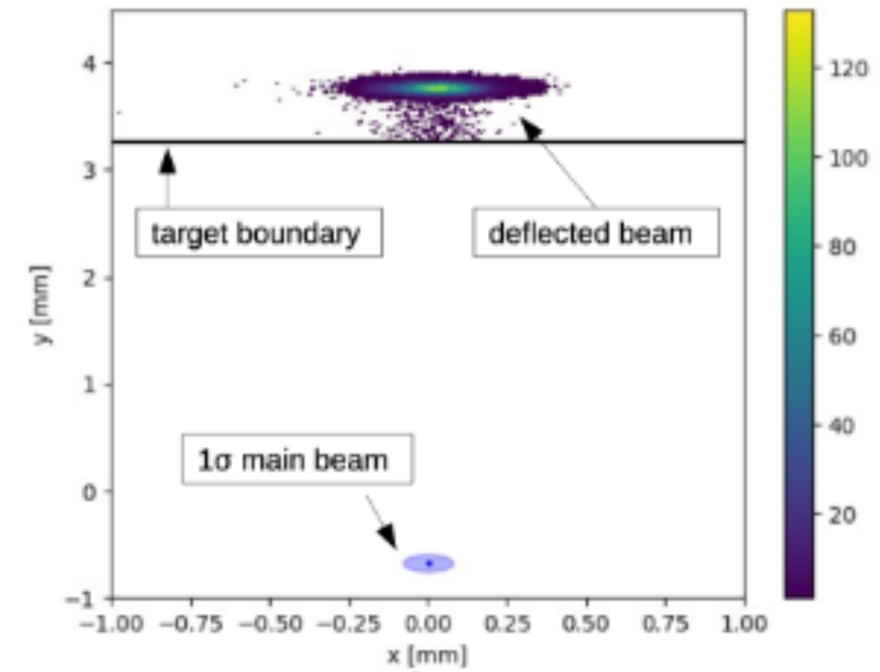


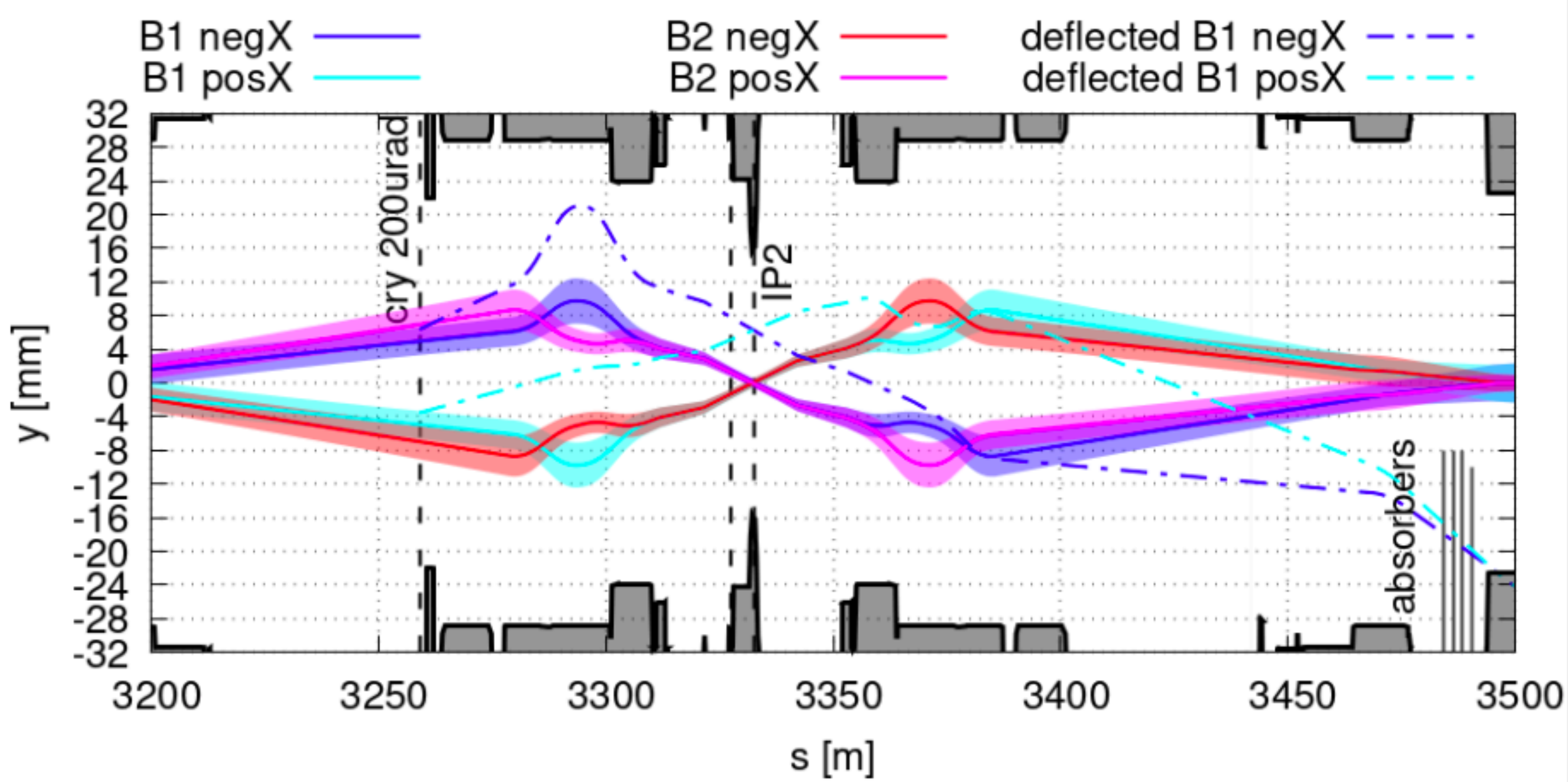
Crystal layout for ALICE

Crystal channeling:

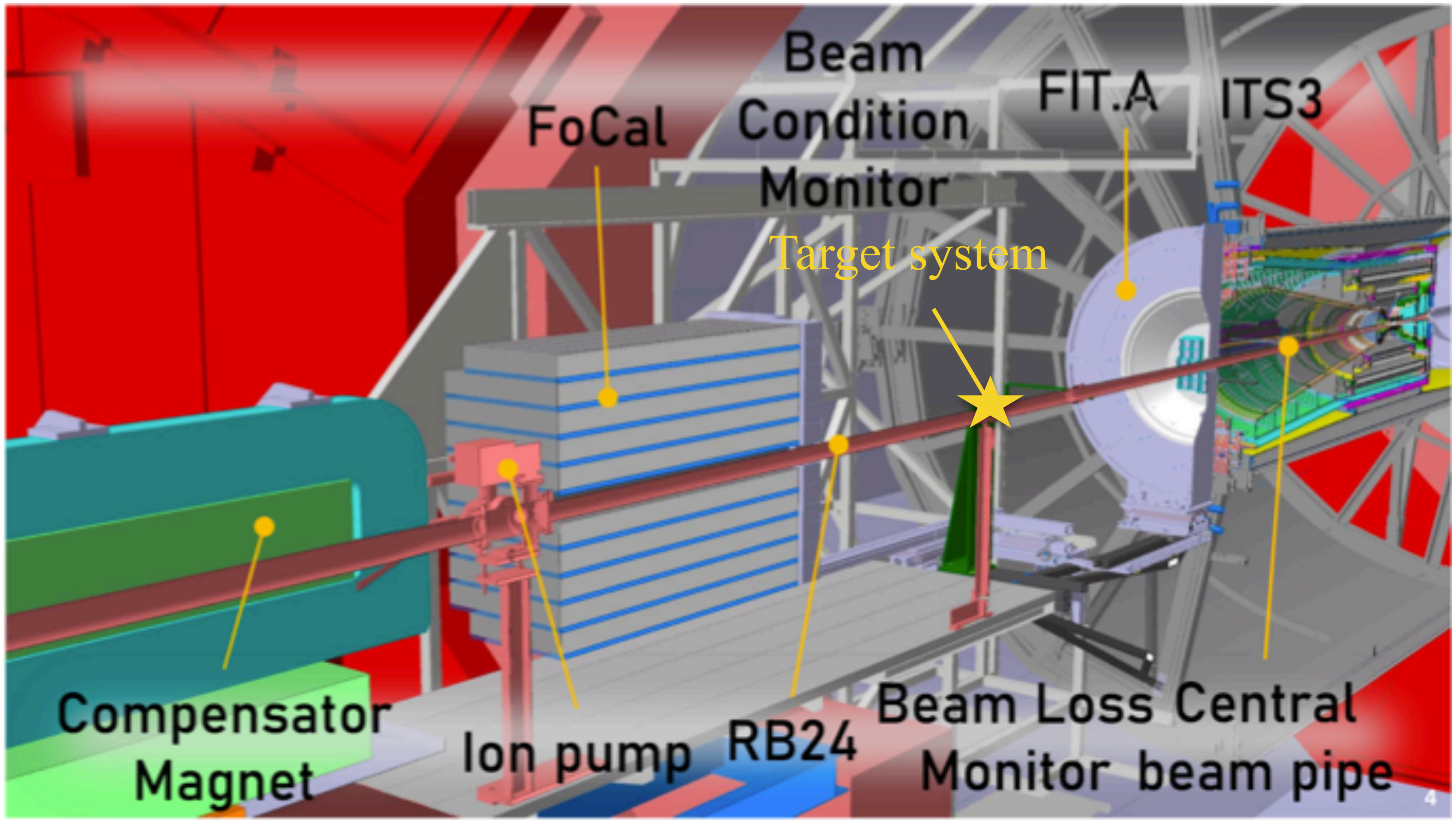
- Proton beam collimation and integration studies performed in collaboration with LHC collimation team
- Deflected halo in the vertical plane, nicely collimated
- Parasitic operation (with respect to all LHC experiments): fixed-target collisions can occur in parallel to beam-beam collisions
- Optimization of the bent crystal setup: provide a maximum flux of protons on target (PoT) to the experiment and keep new LHC loss spikes within acceptable limits
- Expected PoT in Run 4: 10^6 p/s as a minimal limit in parasitic mode
- Lead beam studies started
- Double crystal setup in IR3 during Run 3 with W target proposed by LHC collimation team: essential to validate the simulations

M. Patecki, ICFA HB2021 proceedings





Target system integration

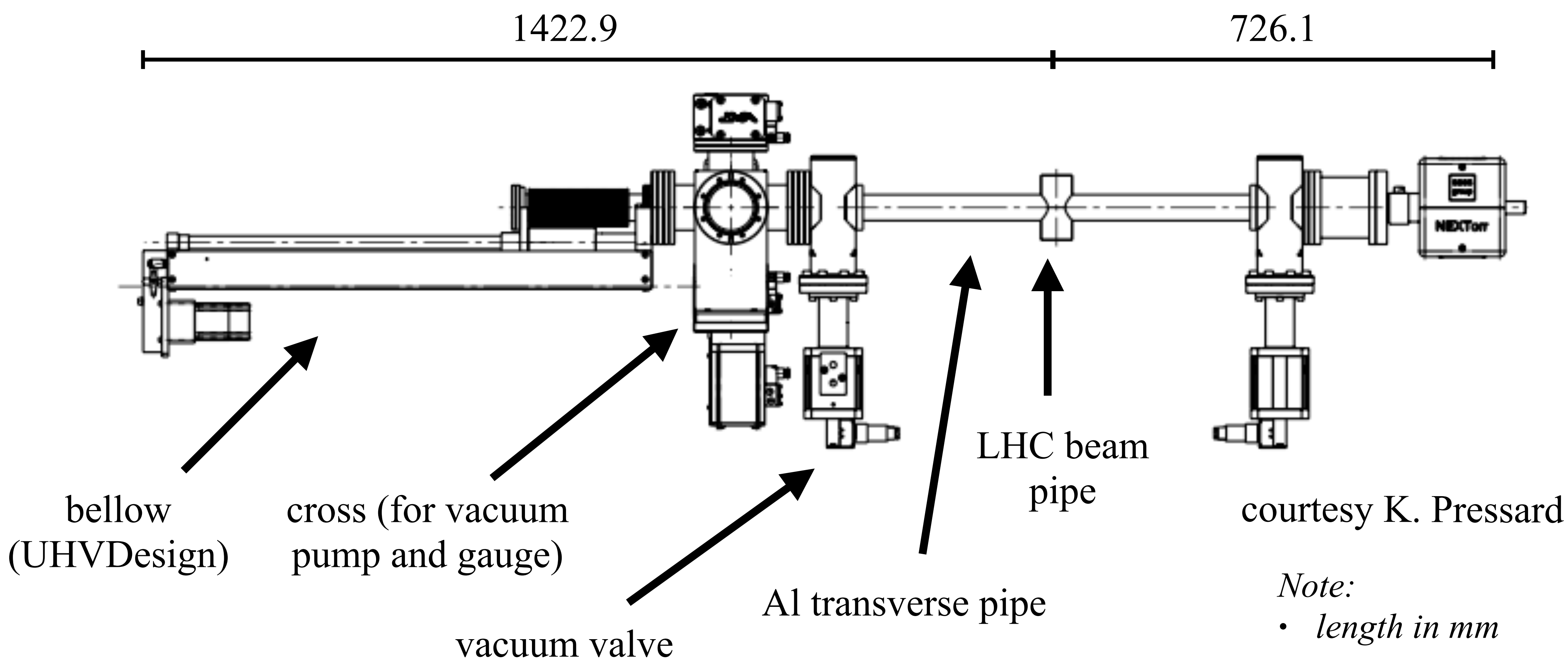


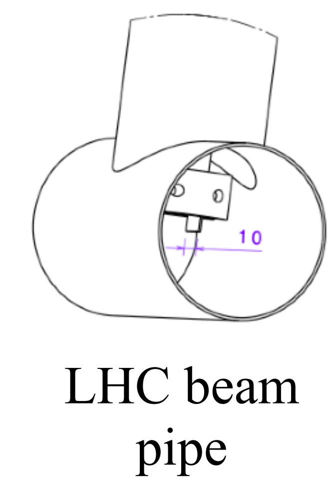
ALICE-FT

- Integration constraints:
  - Implementation as close to IP2 as possible preferable for the physics case
  - ITS3 and FIT.A: possible displacement during End Of Year Technical Stop (EYETS)
    - ➡ z~-4.8 m from IP2 seems feasible with target system in the horizontal plane
  - FoCal detector behind the target system: no shadow to FoCal from target system
- Vacuum constraint:
  - Beam pipe vacuum in IP2~10^{-10}-10^{-11} mbar

Target system design

View from above





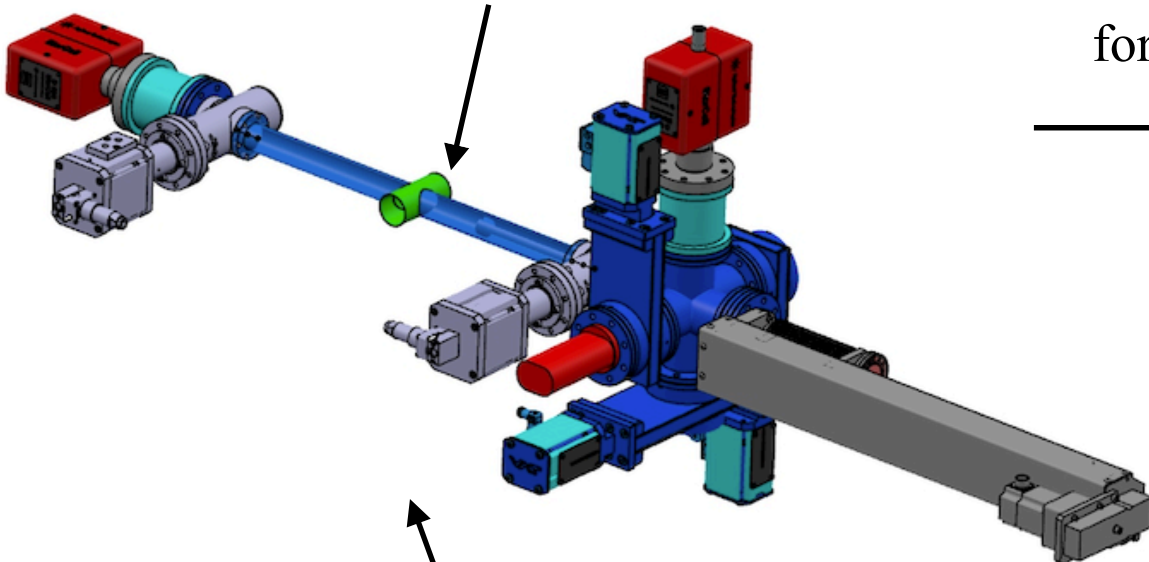
courtesy K. Pressard

Note:
- *length in mm*

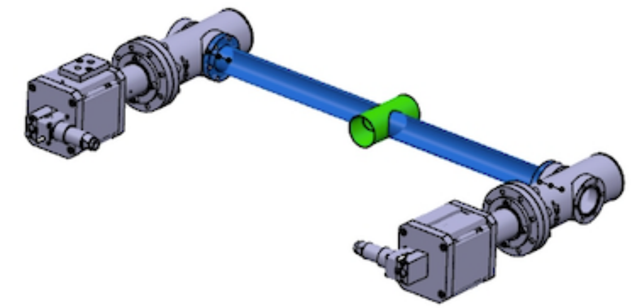
Target system:
- retractable target with linear motion
- target actuator moves thanks to a step motor that compresses a bellow
- step motor to achieve a better movement resolution (10 mm/s with 10 μm accuracy)
- transverse pipes to avoid shadow to FoCal
- vacuum valve closed when target is fully retracted
- crosses, bellow (and target) and vacuum equipment can be removed during EYETS

Target system design and EYETS operations

LHC beam pipe

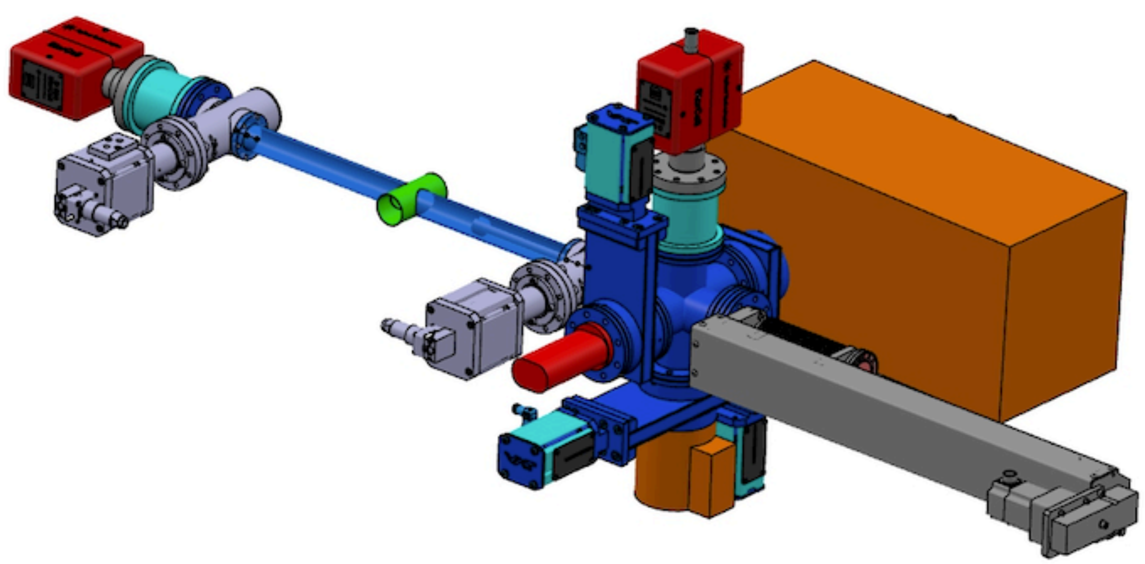


for ITS removal



for vacuum pumping (10^{-11} mbar)

preparation for data taking

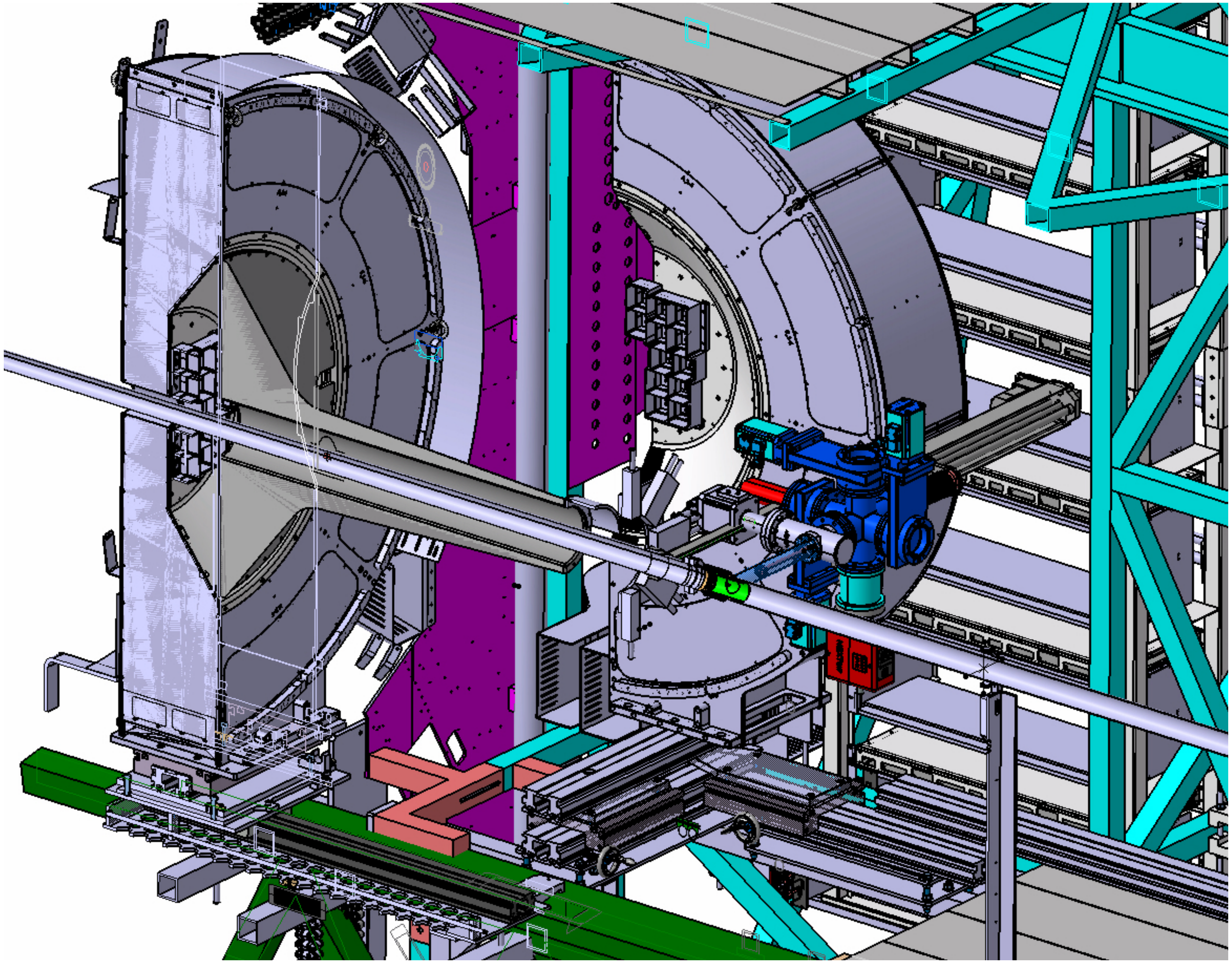


Pumping system:

- primary
- secondary
- ion pump
- gauge
- about 1 week of operation

Integration in mini-frame

IP2

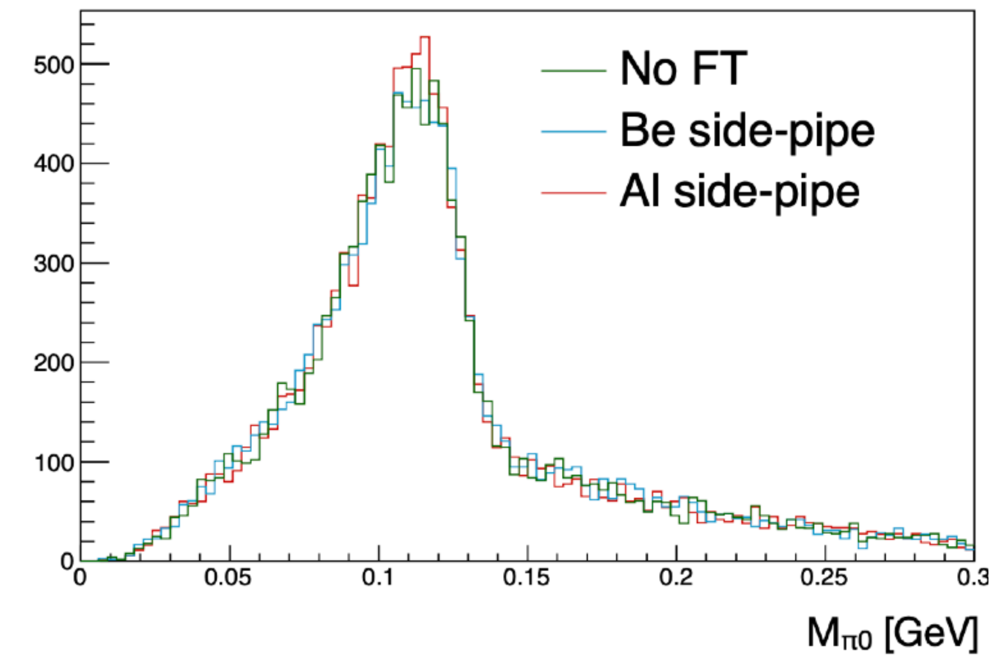


z = 4950 mm

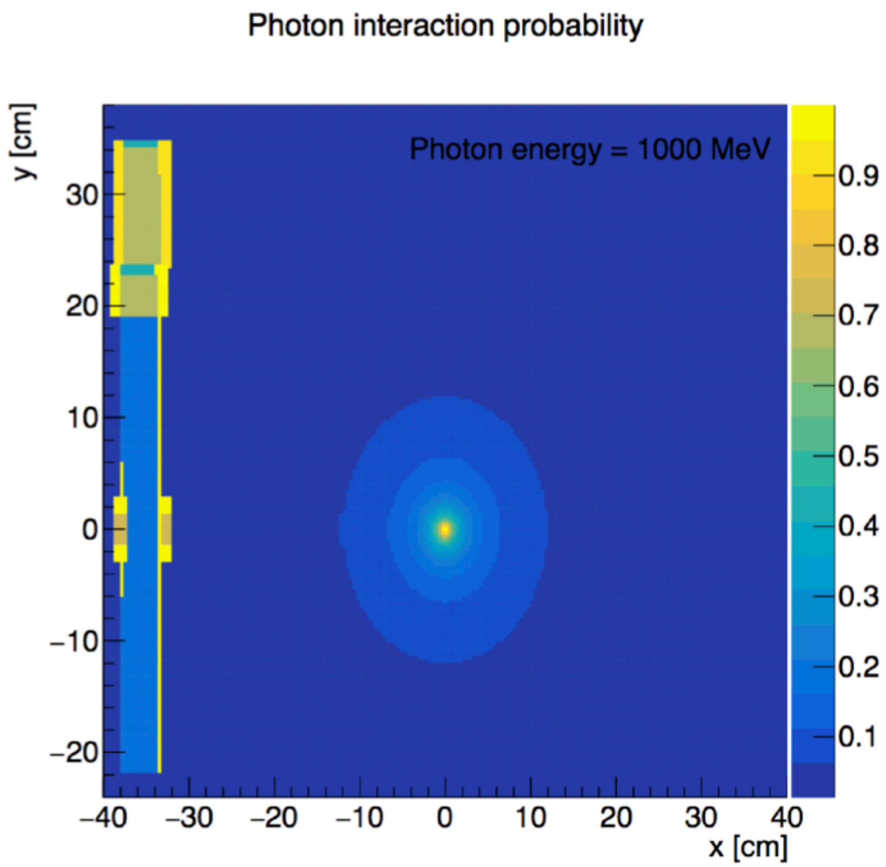
- target system fits into mini-frame with the current design

Impact on FoCal

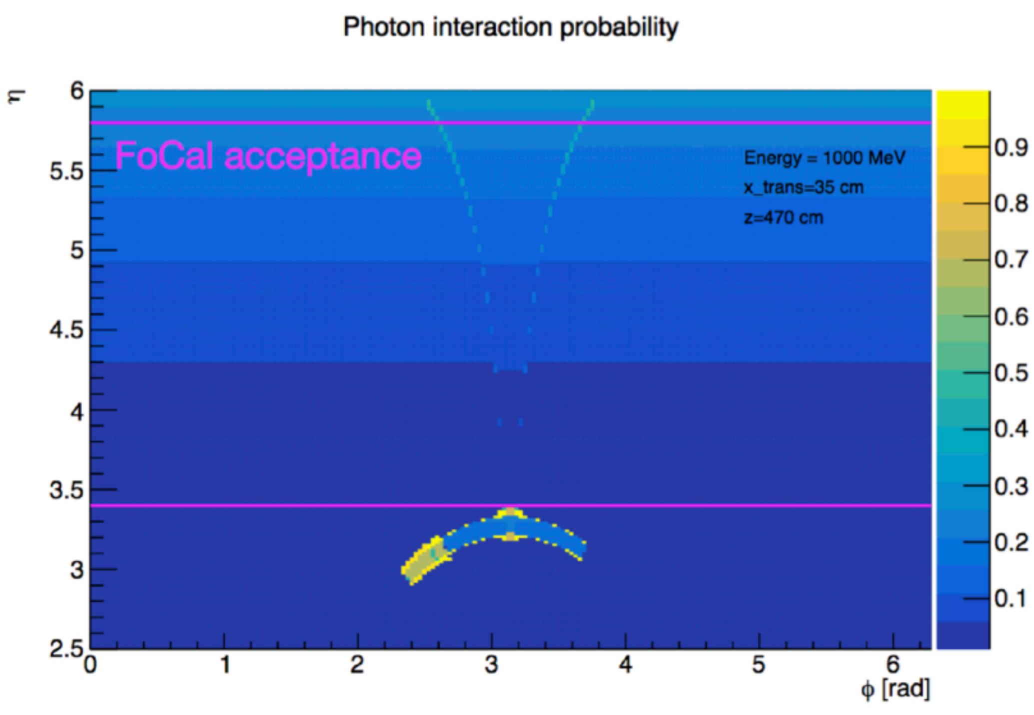
- Large photon interaction probability with the vacuum valve of the target system: valve to be placed at about 30 cm from the beam pipe
- π^0 full simulation reconstructed with FoCal and the target system: no effect from the vacuum valve and Al transverse pipe



LHC beam pipe and transverse pipe=0.8 mm thick Be



z=470 cm from IP



C. Van Hulse

Target system design optimisation: next steps

Vacuum studies (2023):

- Target system outgassing during operation
- Pressure profile at $z = z_{target}$
- Vacuum equipment studies

Beam impedance studies (2023):

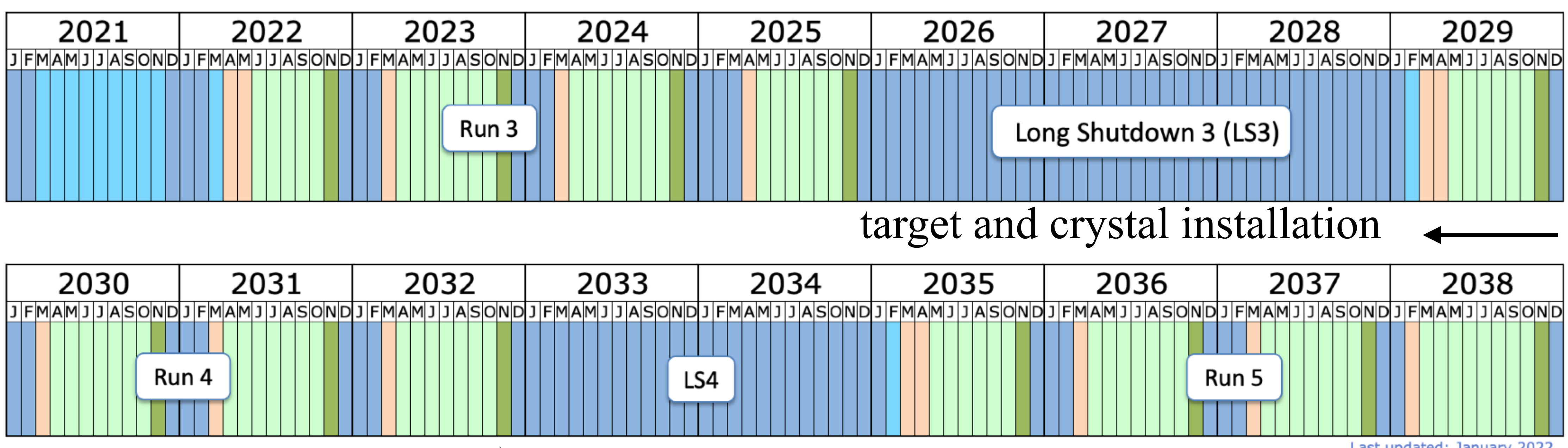
- Impedance calculation at $z = z_{target}$
- RF shielding

Build an evolutive target system prototype at Orsay (2023/2024)

- Target motorisation and mechanical studies
- Target system vacuum studies

National funding (ANR MALICE from Laure Massacrier): physics, vacuum and impedance studies

- Will complete the P2IO funding for impedance studies and for building a prototype



target and crystal installation ←

ALICE-FT →

Outlook

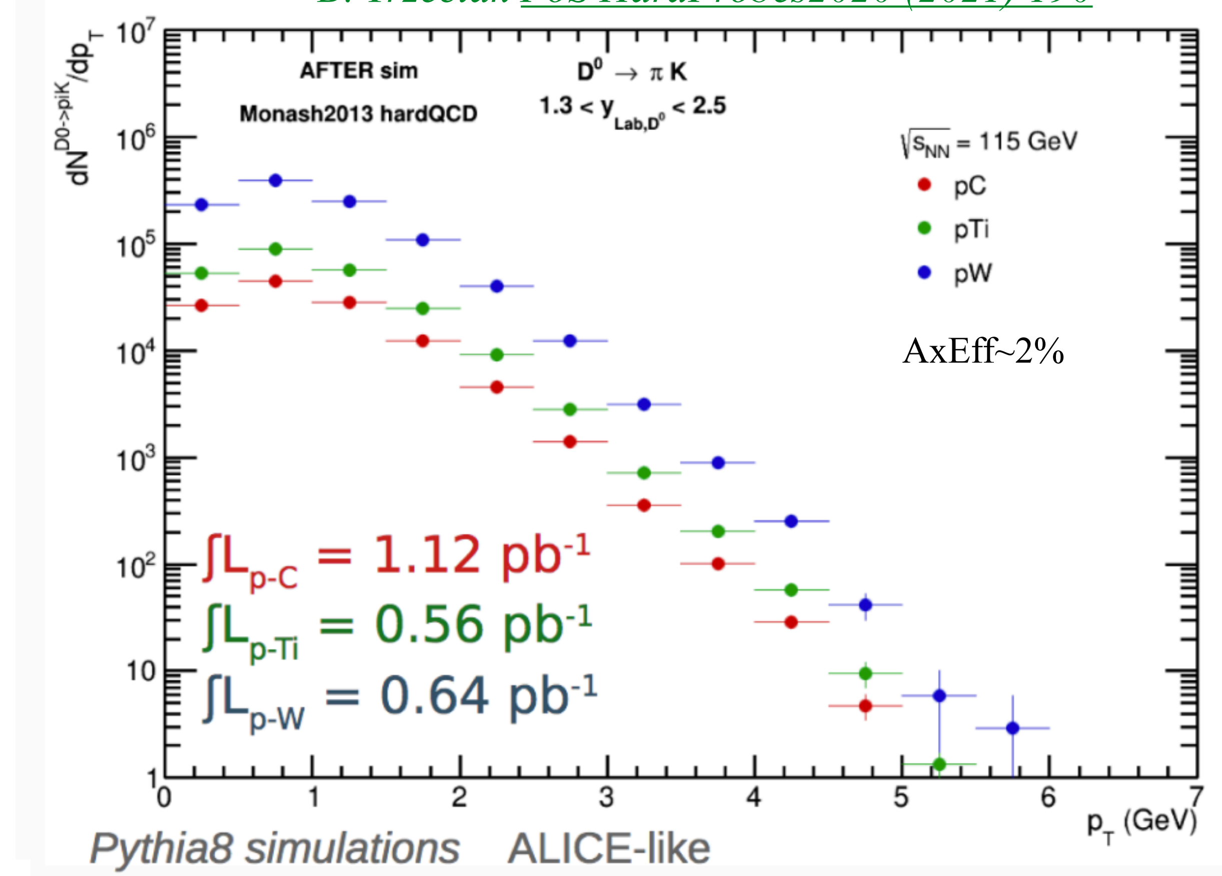
- Main physics motivations for a high-luminosity fixed-target experiment with ALICE at LHC (ALICE-FT):
  - –**High-*x* frontier**: nucleon and nuclear structure and connections with astroparticles
  - –**Quark Gluon Plasma** over a broad rapidity domain

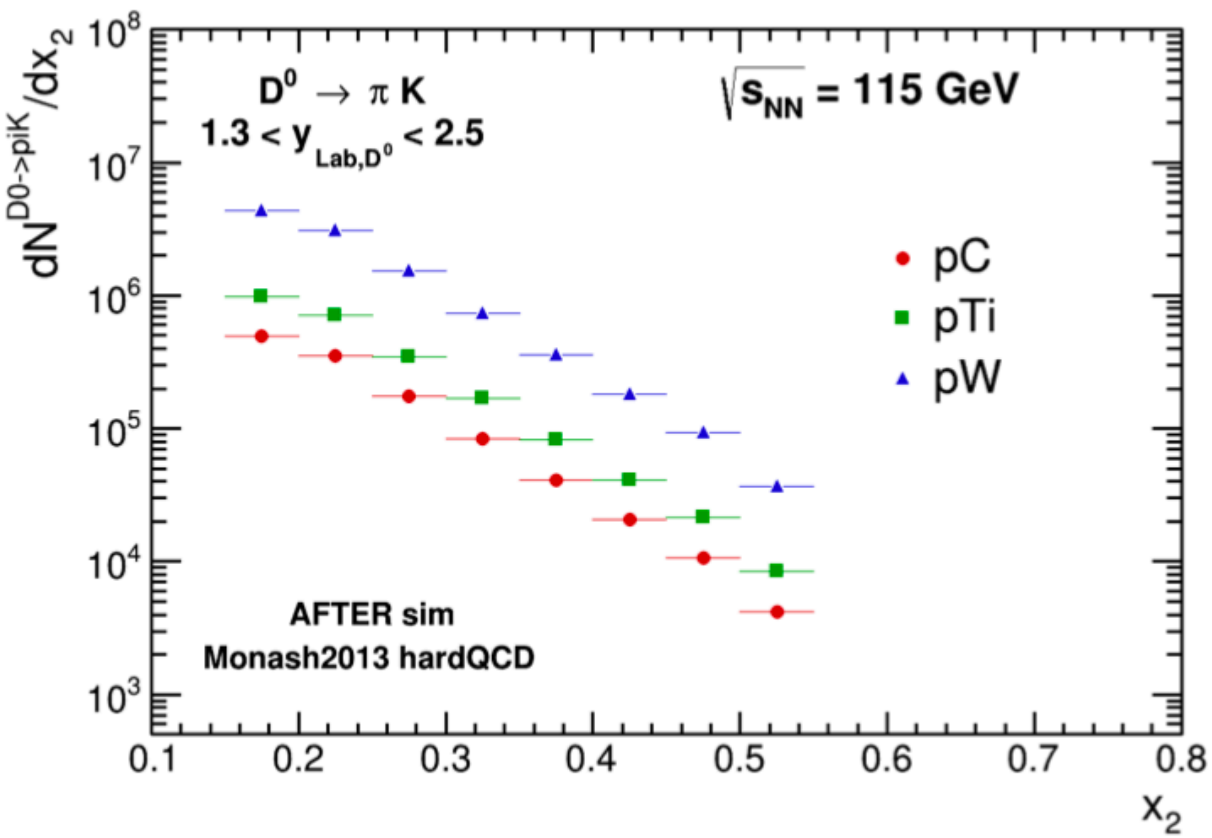
- Compelling physics case for a fixed-target programme in ALICE (ALICE-FT project)
  - –bent crystal layout with proton beam provide large proton flux. Lead beam studies started.
  - –target system conceptual design ongoing, vacuum and impedance studies to be started, real evolutive prototype to be built at Orsay

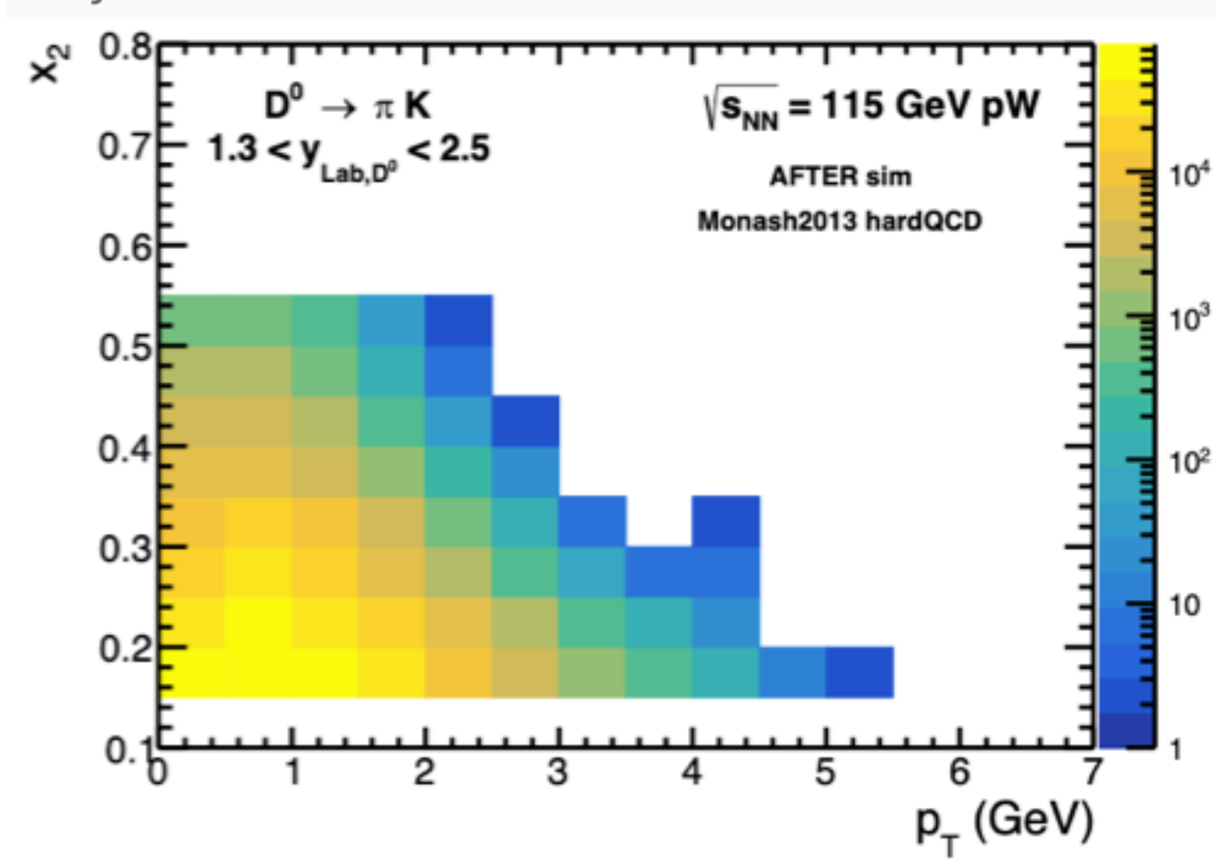
Opportunities with ALICE-FT with proton beam

- Investigate large-*x* gluon nPDFs (assuming nPDF modification is the largest Cold Nuclear Matter effect, also need pH reference)
- Precise pA measurements with the central barrel up to $p_T \sim 4$ GeV/c
- Target x_2 coverage: 0.15-0.45

B. Trzeciak PoS HardProbes2020 (2021) 190





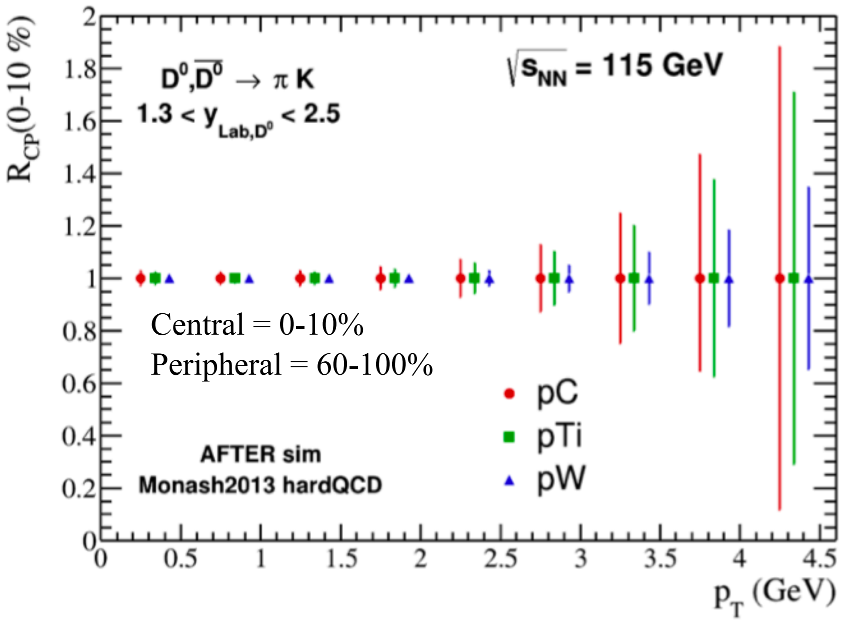


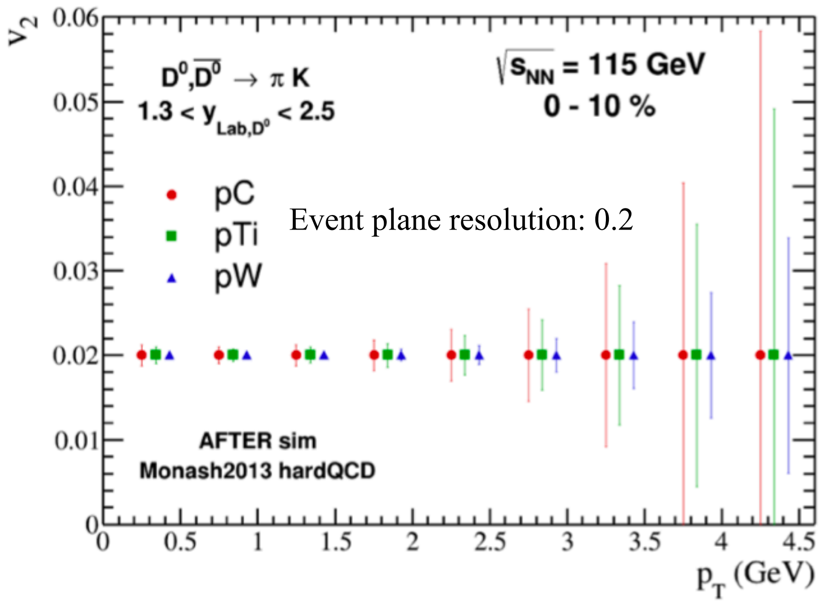
Opportunities with ALICE-FT with proton beam

B. Trzeciak ***PoS HardProbes2020 (2021) 190***

Charm production in pC, pTi and pW

- Study of Cold Nuclear Matter effects and possible collectivity in small systems with simultaneous measurements of D meson R_{CP} and v_2 in different systems

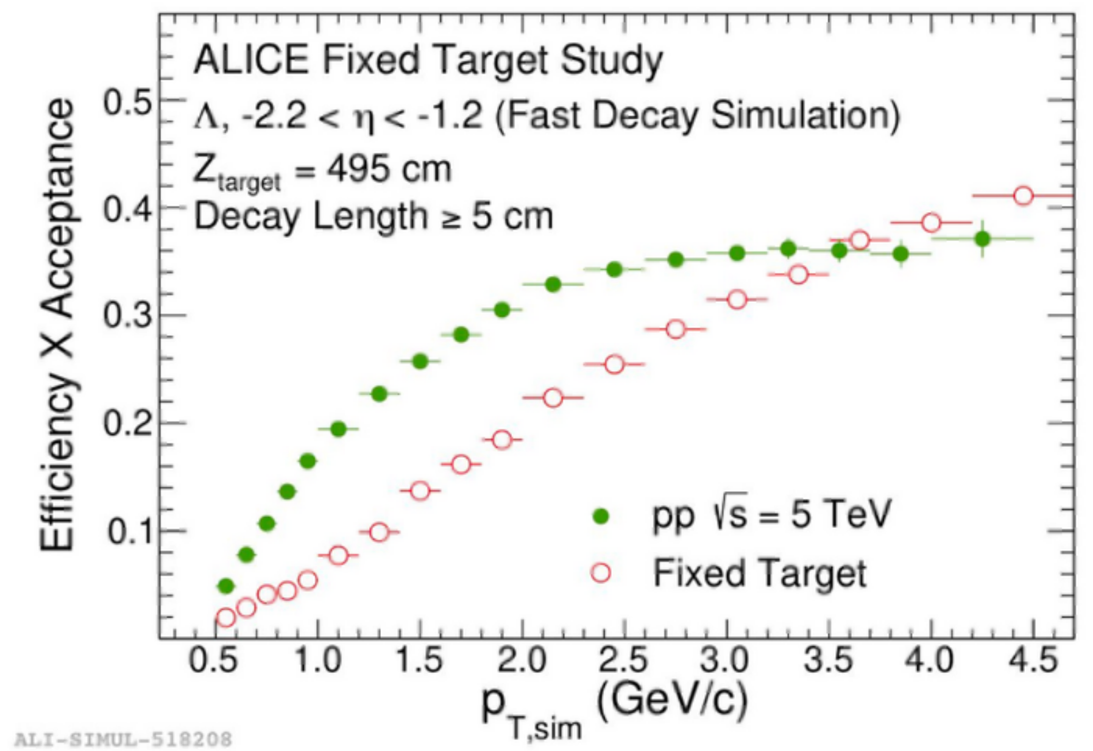




- Precise R_{CP} measurements up to $p_T \sim 3$ GeV/c
  - Similar expected precision in 10-20% and 20-40% centrality classes
- Precise flow measurements up to $p_T \sim 3$ GeV/c

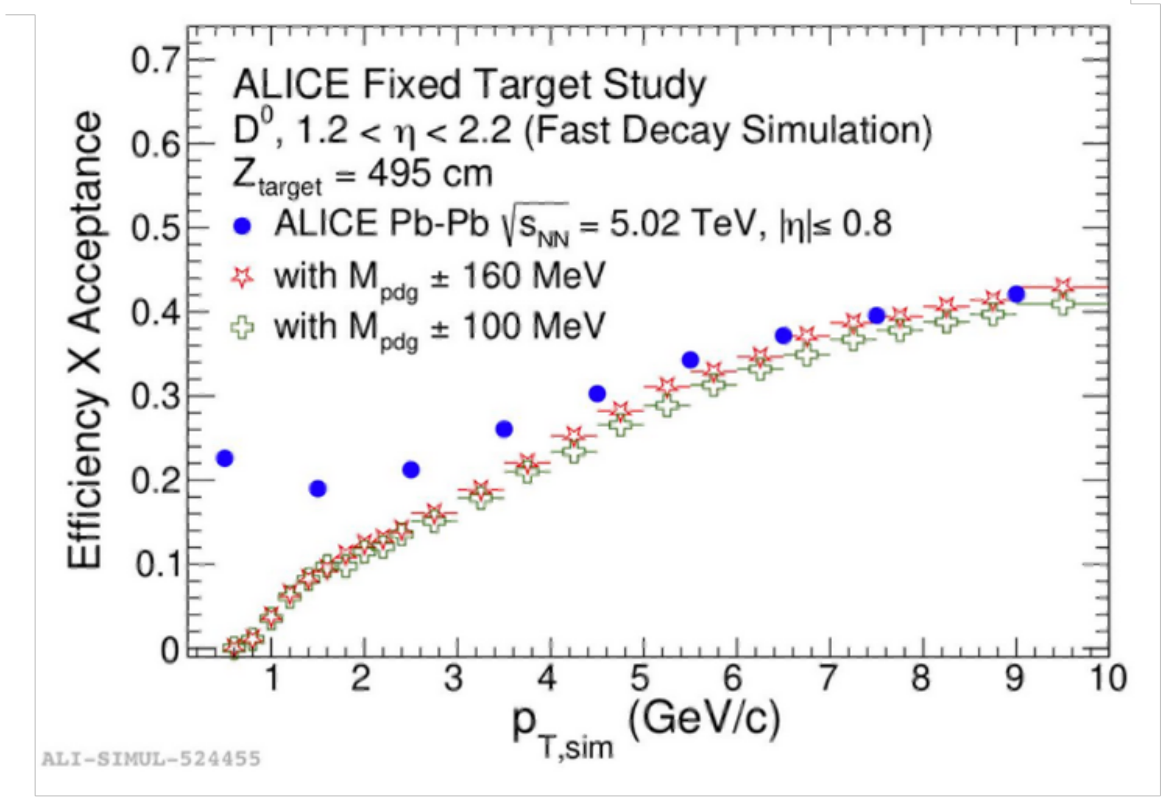
Recent ALICE-FT performance studies

ALICE-FT physics motivations *ESPP document*



Λ and D^0 simulations

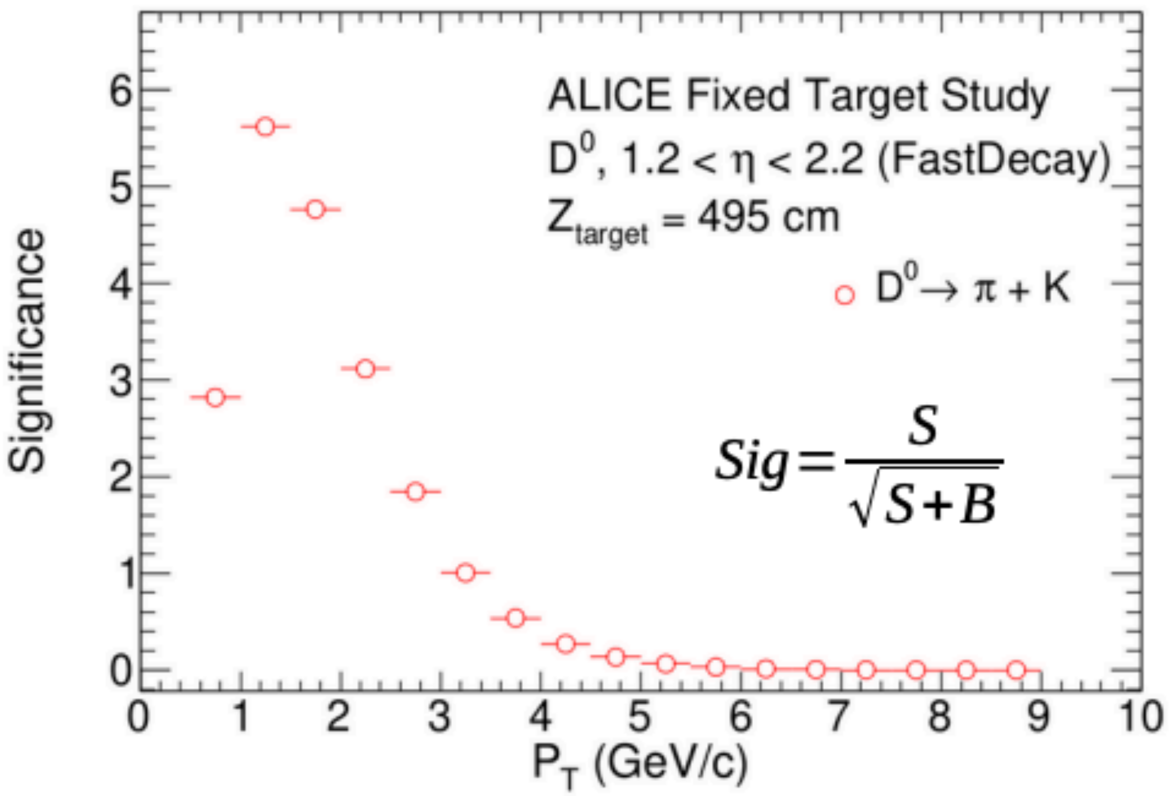
- Tracking and vertexing with ALICE TPC
- Fast decay simulations in p+W at $\sqrt{s_{NN}}$ = 115 GeV
- Λ as a probe for strangeness content of nucleon/ nuclei (selection on decay length > 5 cm and p+π invariant mass)
- D^0 as a probe for gluon/intrinsic charm content of nucleon/nuclei (selection on K+π invariant mass)
- Efficiency lower than in collider mode but sufficient to for D^0 and Λ production studies without additional vertex detector

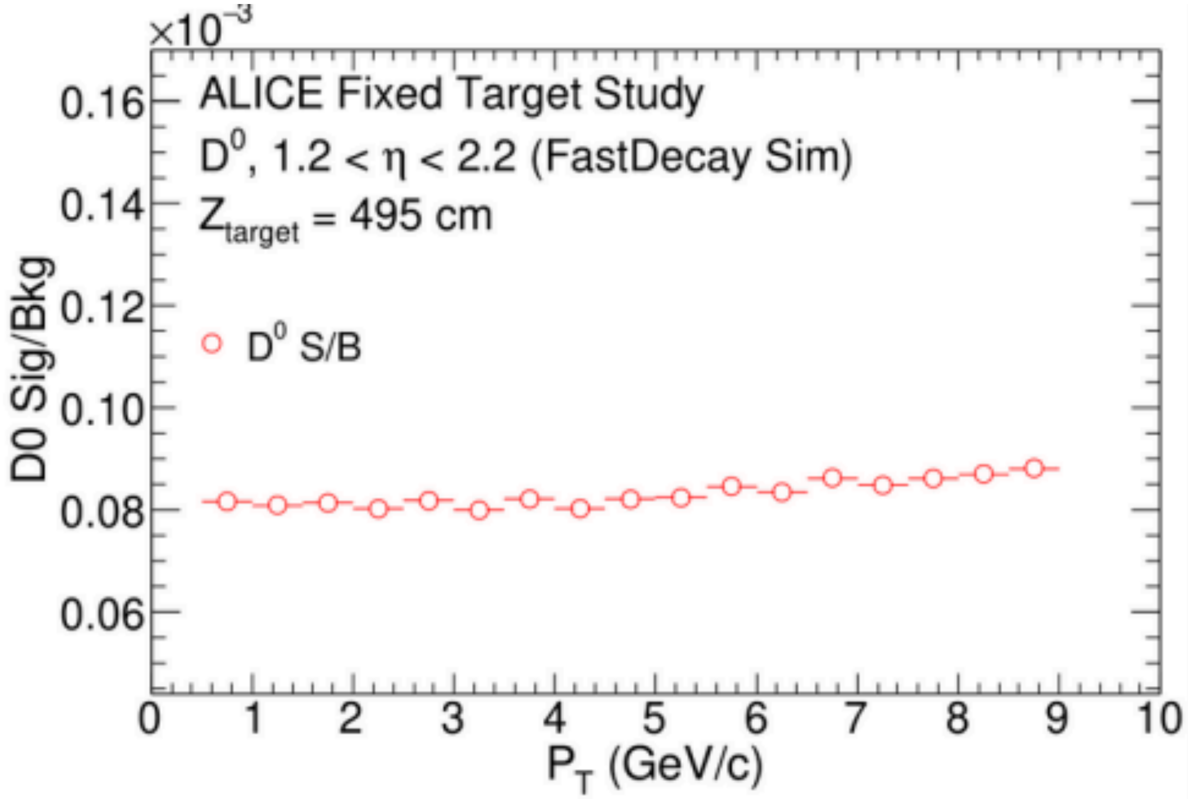


Recent ALICE-FT performance studies

D^0 significance and S/B ratio

- Fast decay simulations in p+W at $\sqrt{s_{NN}}$ = 115 GeV for one year of data taking
- Measurement of charm cross section feasible without additional vertex detector
- Results with Run 3 geometry (larger material budget compared to Run 4) : possibility to improve S/B



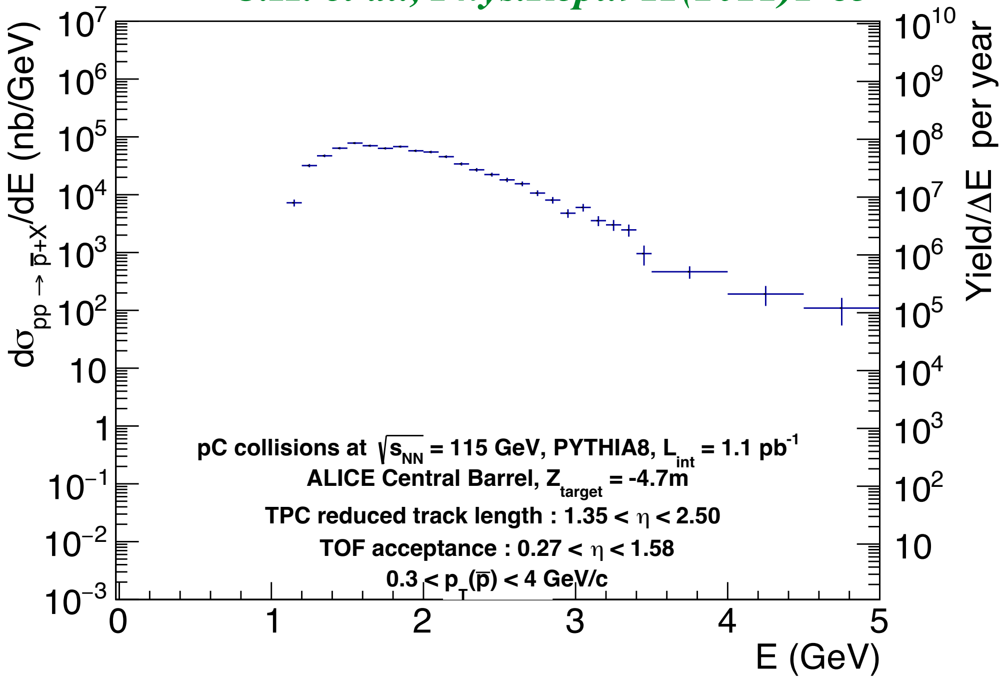


Opportunities with ALICE-FT with proton beam

Antiproton in pC collisions

- Use inverse kinematic:
  - p/^{4}He/^{12}C/^{14}N/^{16}O/… (CR) + H (at rest) → antiproton of large E
  - Equivalent to (inverse kinematic): p (7 TeV beam) + p/^{4}He/^{12}C/^{14}N/^{16}O/… (at rest) → antiproton of small E
  - Complementary measurement with respect to LHCb
- Very low proton energy accessible with the central barrel with large yields

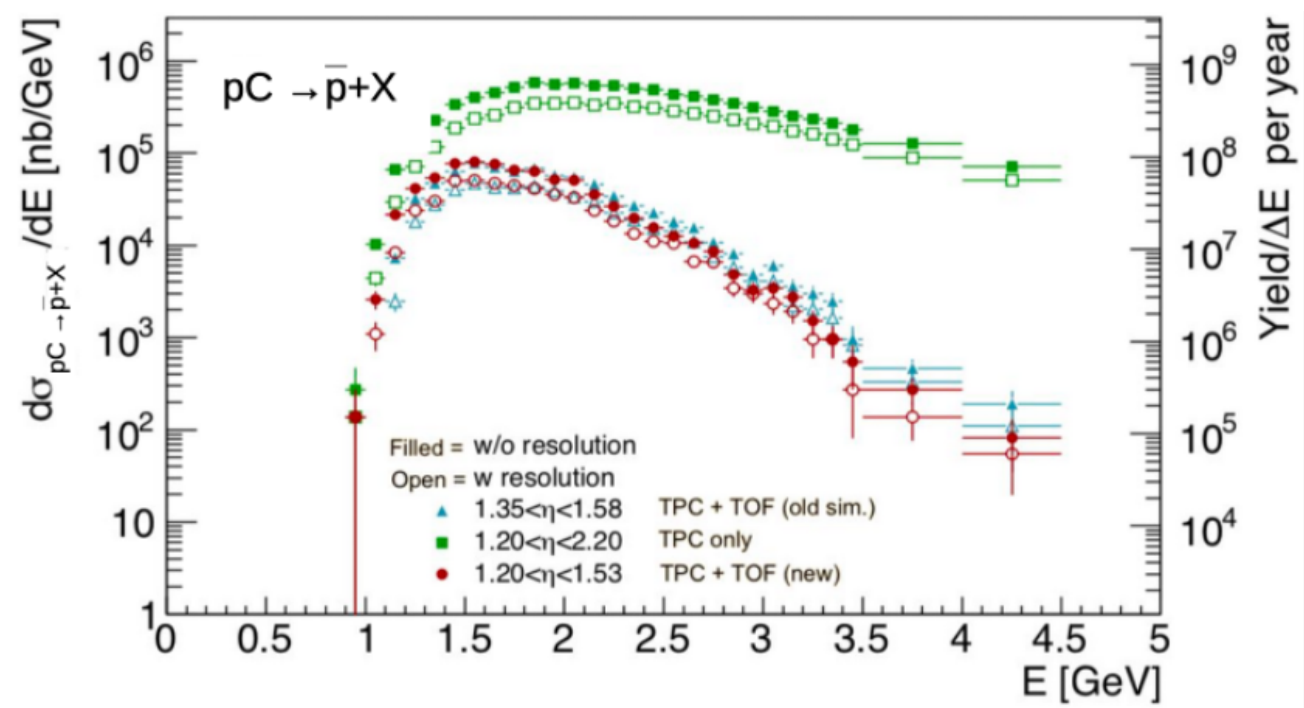
C.H. et al., Phys.Rept.911(2021)1-83

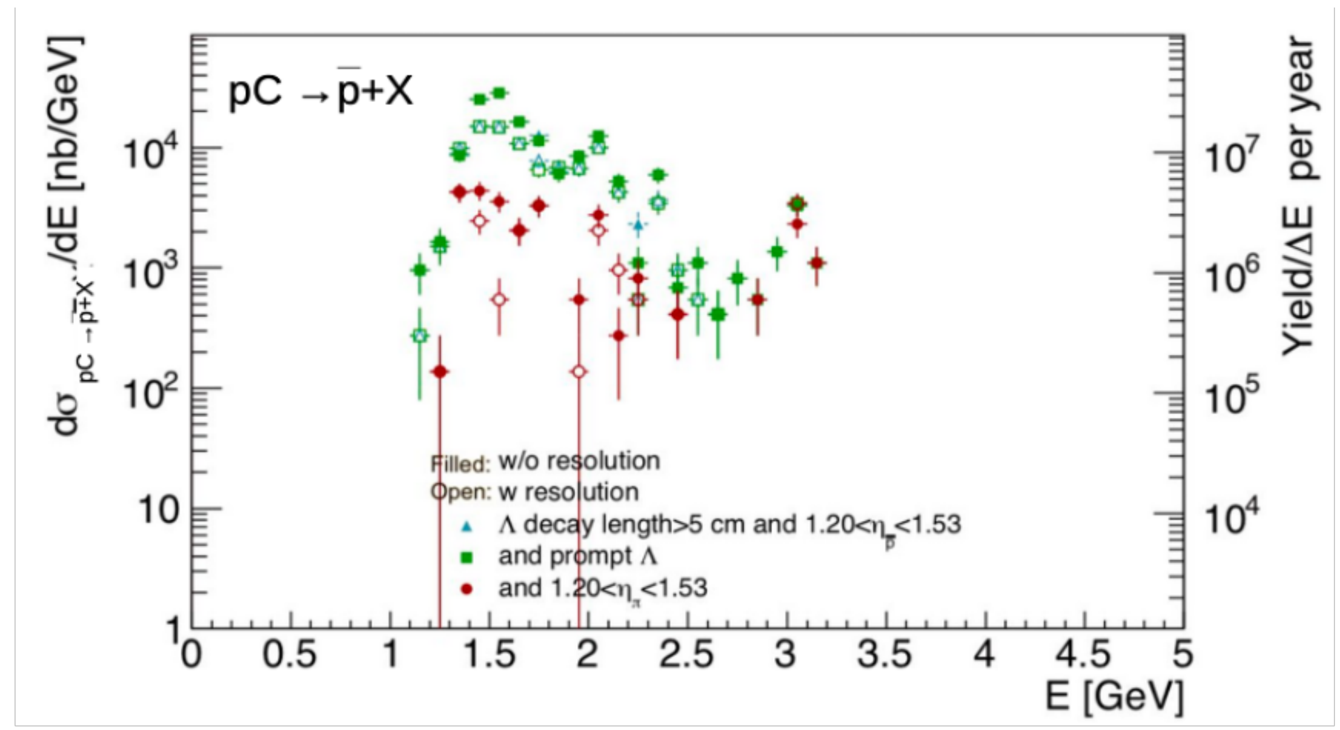


Recent ALICE-FT performance studies

Antiparticules simulations

- Antiproton important input for theoretical calculations of secondary cosmic antiproton spectrum:
  - p+C (target) → antiproton of low E: inverse kinematic process of high energetic C+H (target) → antiproton of large E
- Simulations include detector efficiency and acceptance
- Large yield expected in the TPC and TOF
- Antiproton feed-down could be as well measured by measuring anti-Λ (Anti-Λ → antiproton + π)
- Estimation of the PID performance with TPC and TOF ongoing



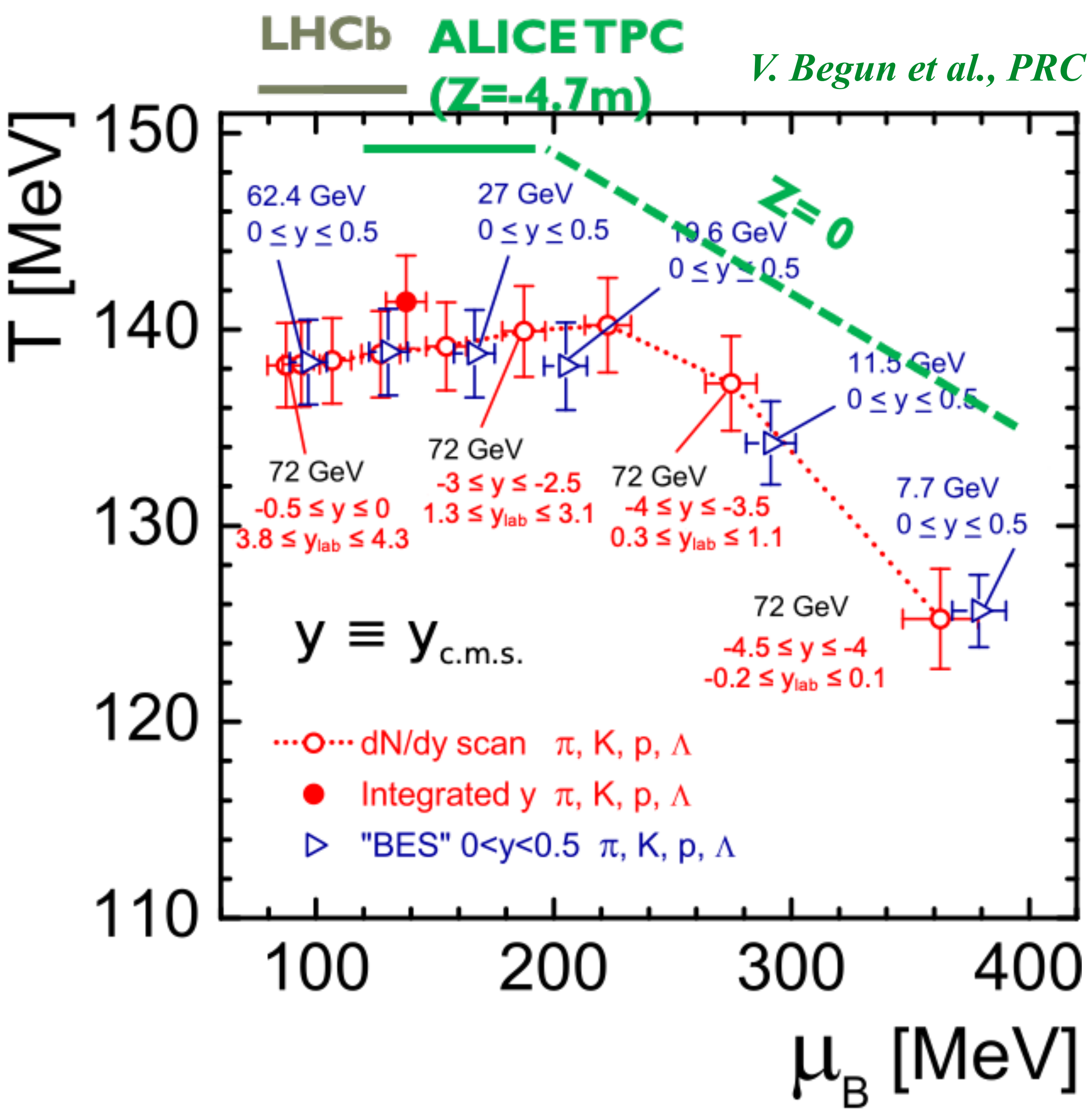


Opportunities with ALICE-FT with lead beam

Rapidity scan in heavy-ion collisions

- A rapidity scan at 72 GeV with FT@LHC complements the RHIC beam energy scan
- Study of identified particles can be performed at backward y_{cms} in ALICE, in complementarity to LHCb

V. Begun et al., PRC 98 (2018) 034905



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